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(54) Abstract Title
Voltage controlled oscillators

(57) Frequency modulation of a VCO's output is achieved by a modulating voltage (VM) fed to the oscillator's control line through an attenuator (28). In a preliminary measurement, the loop sensitivity of the VCO is measured at a number of frequency values (F1, F3, F5,..Fn) distributed over the VCO's characteristic. This is done by setting the VCO to operate at each frequency (F1, F3, F5,..Fn) in turn, and measuring the amount of control line voltage change which corresponds to a measured small change in the VCO output frequency at that frequency (F1, F3, F5,..Fn). For each of these loop sensitivity values, the deviation sensitivity D of the VCO to a change in the modulating voltage (VM) is calculated. Finally, the attenuator settings (A1, A3, A5,..An) necessary to provide a target VCO frequency modulation at each frequency (F1, F3, F5,..Fn) can be calculated using the calculated deviation sensitivities (D1, D3, D5,..Dn) and knowledge of the maximum value of the modulating signal (MS). From these calculated attenuator settings (A1, A3, A5,..An), the attenuator setting A_F at any operating frequency F can be estimated, for example by interpolation. The oscillator may be used in a mobile radio or telephone.

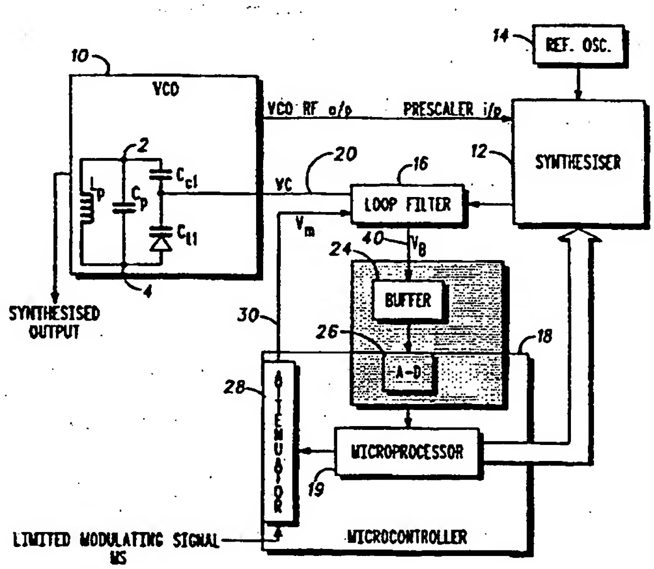

FIG.4

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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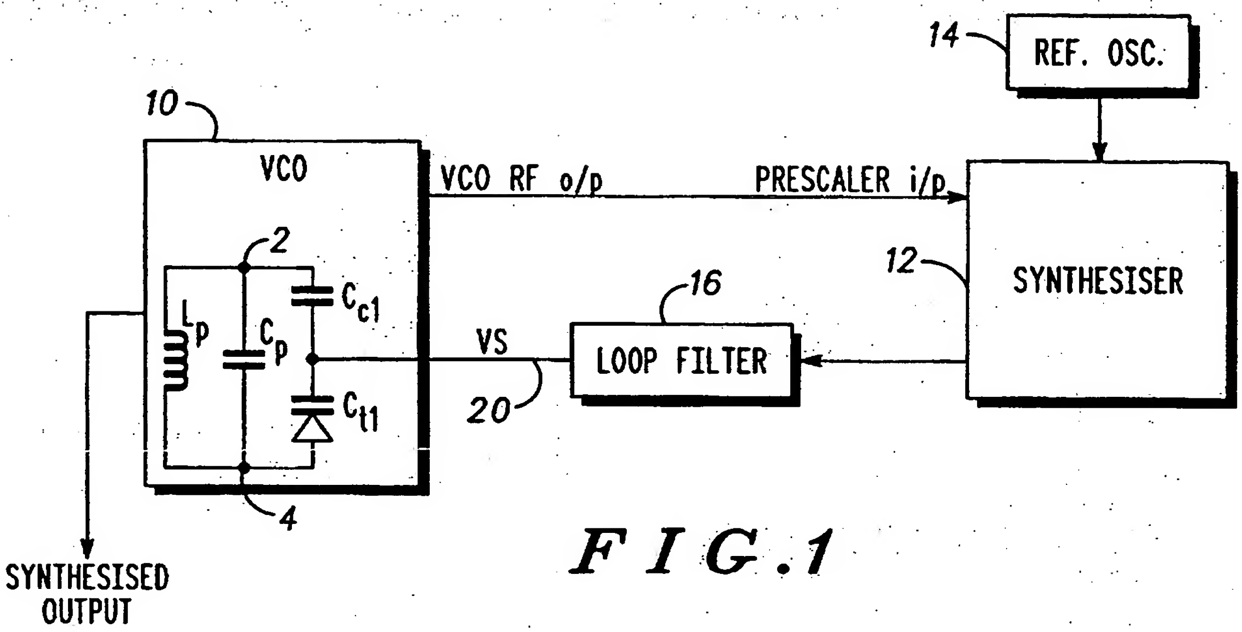

14
REF. OSC.
10
VCO
VCO RF o/p
PRESCALER i/p
2
C_{c1}
L_p
C_p
12
SYNTHESISER
16
VS
LOOP FILTER
C_{t1}
20
4
SYNTHESISED OUTPUT

FIG. 1

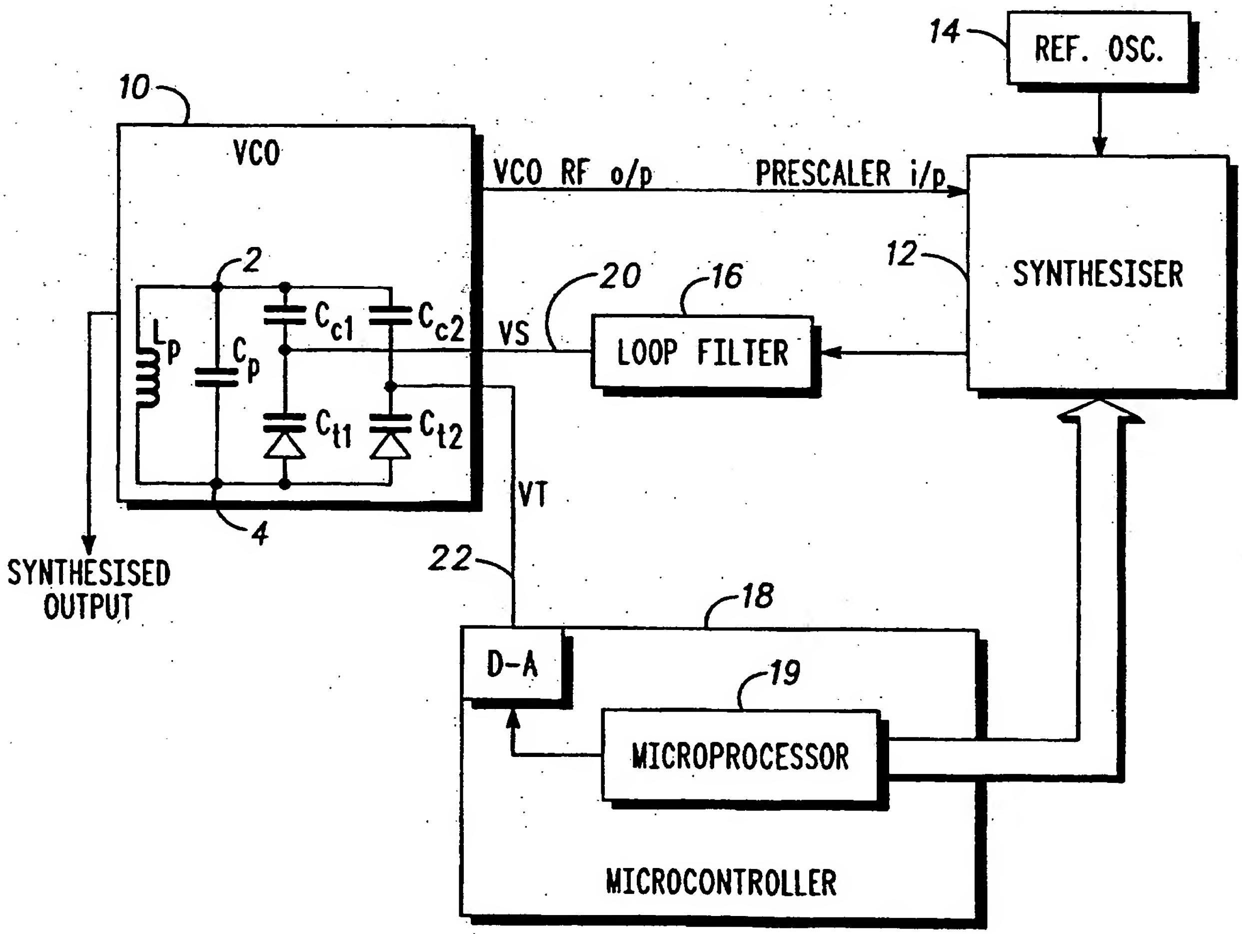

14
REF. OSC.
10
VCO
VCO RF o/p
PRESCALER i/p
12
SYNTHESISER
2
20
16
C_{c1}
C_{c2}
VS
LOOP FILTER
L_p
C_p
C_{t1}
C_{t2}
VT
4
SYNTHESISED OUTPUT
22
18
D-A
19
MICROPROCESSOR
MICROCONTROLLER

FIG. 2

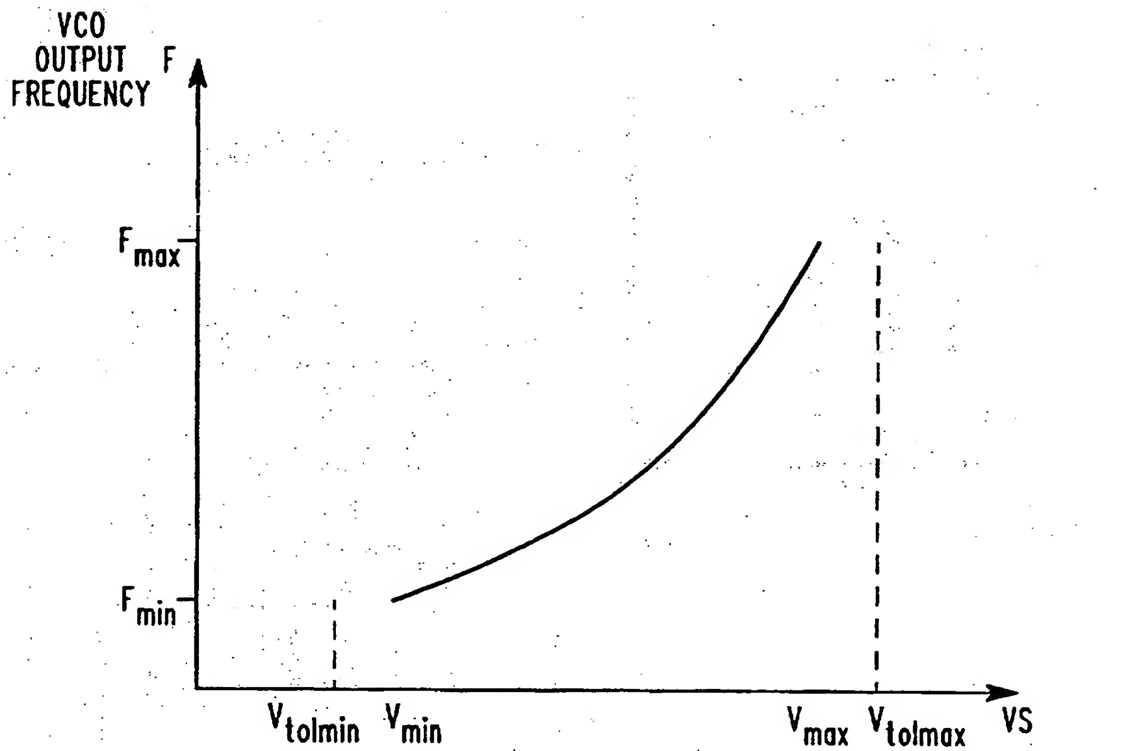
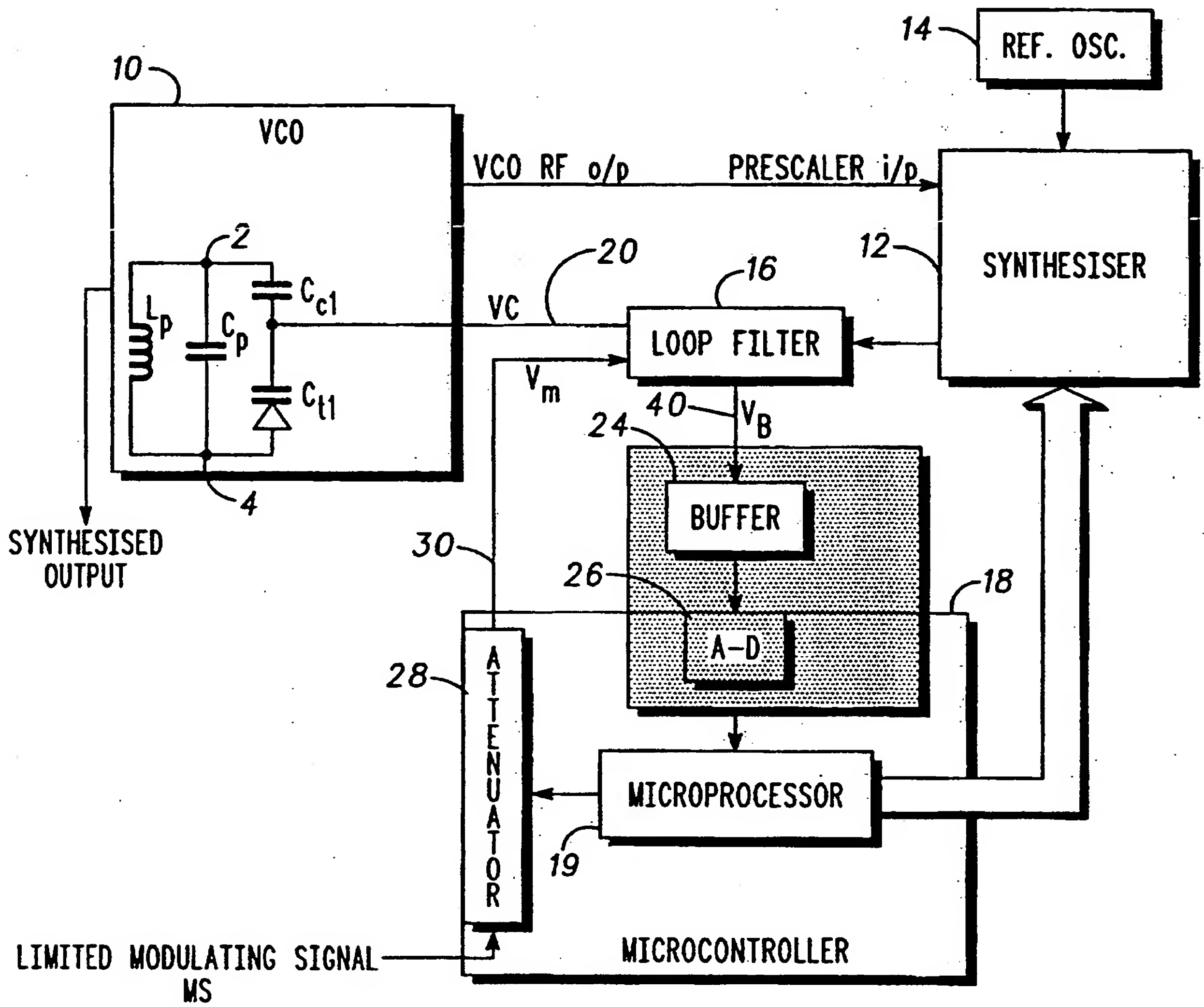

VCO
OUTPUT F
FREQUENCY
F_{max}
F_{min}
V_{tolmin}
V_{min}
V_{max}
V_{tolmax}
VS
STEERING VOLTAGE

FIG.3



14
REF. OSC.
10
VCO
VCO RF o/p
PRESCALER i/p
12
SYNTHESISER
2
C_{c1}
L_p
C_p
C_{t1}
20
VC
16
LOOP FILTER
V_m
40
V_B
24
4
BUFFER
SYNTHESISED OUTPUT
30
26
18
A-D
28
ATTENUATOR
MICROPROCESSOR
19
LIMITED MODULATING SIGNAL MS
MICROCONTROLLER

FIG. 4

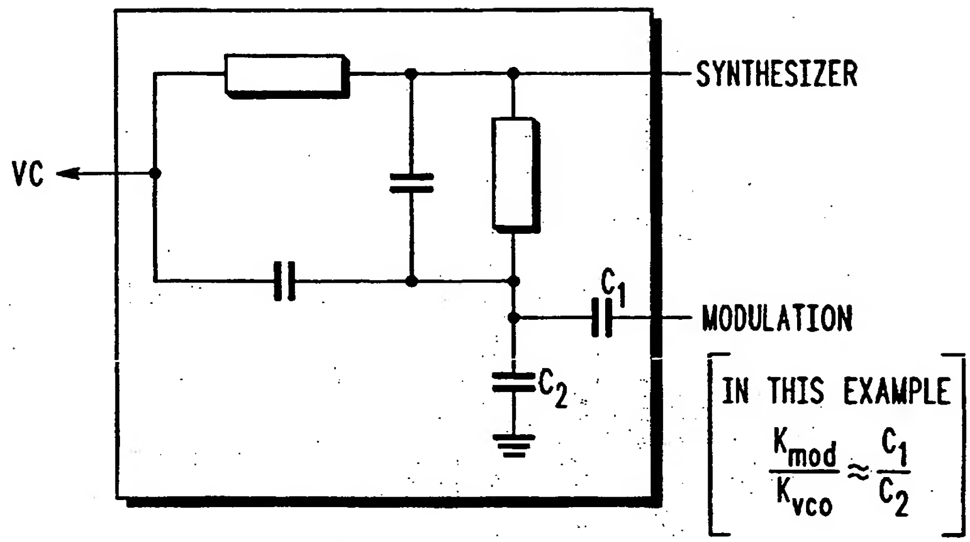

SYNTHESIZER
VC
C_1
MODULATION
C_2
IN THIS EXAMPLE
$\frac{K_{mod}}{K_{vco}} \approx \frac{C_1}{C_2}$

FIG.5

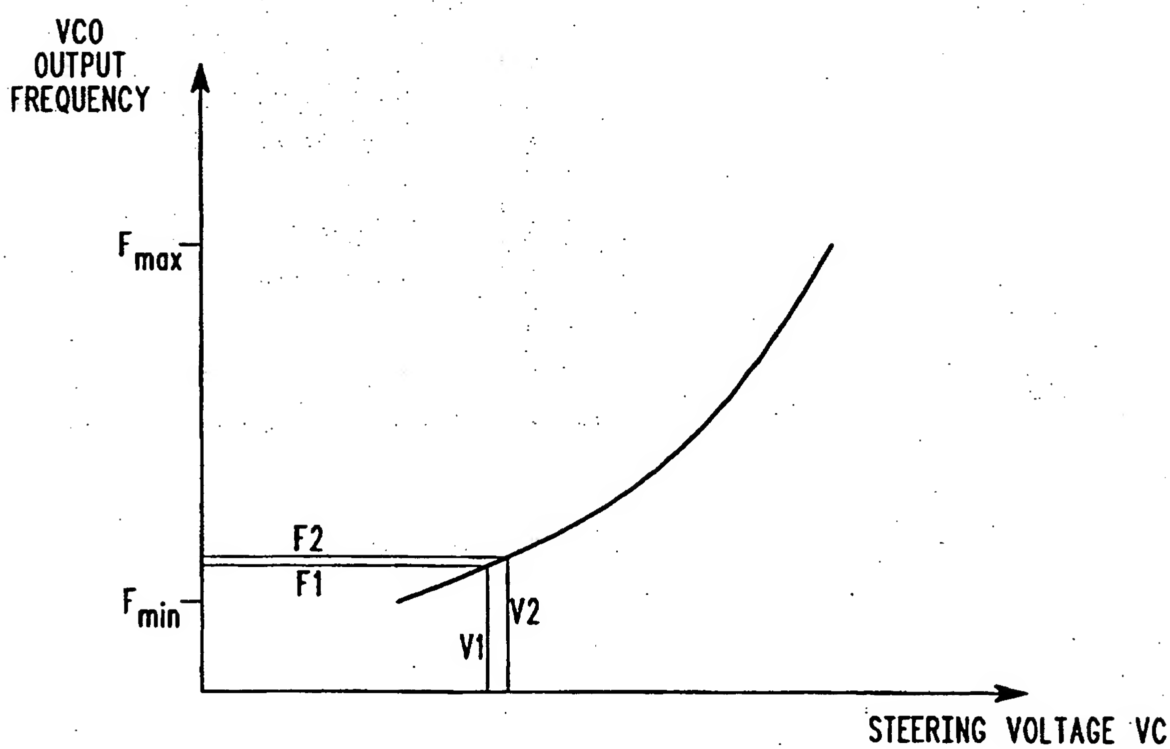
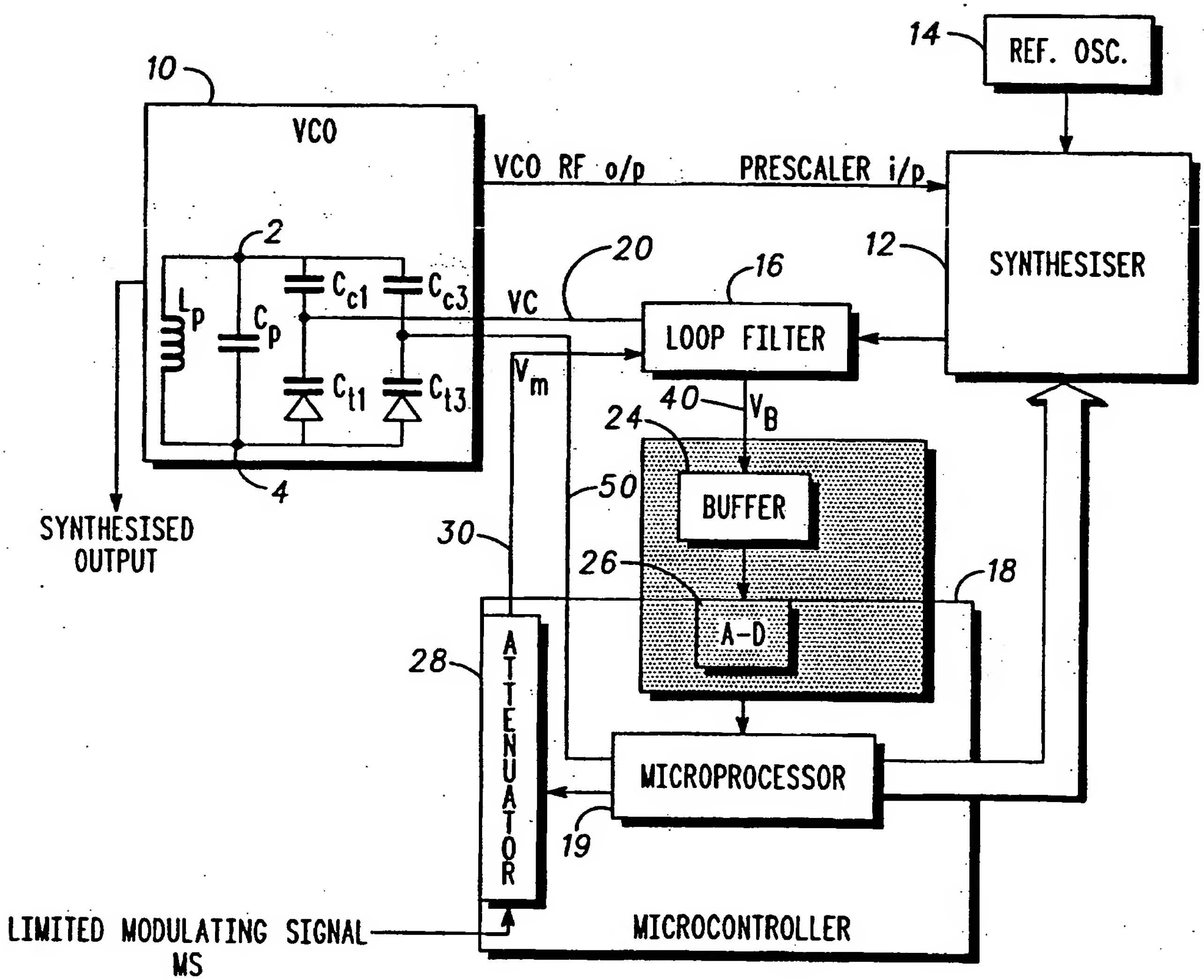

VCO
OUTPUT
FREQUENCY
F_{max}
F2
F1
F_{min}
V2
V1
STEERING VOLTAGE VC

FIG.6



10
VCO
VCO RF o/p
PRESCALER i/p
14
REF. OSC.
12
SYNTHESISER
2
L_p
C_p
C_{c1}
C_{c3}
C_{t1}
C_{t3}
VC
20
16
LOOP FILTER
V_m
40
V_B
24
4
BUFFER
50
SYNTHESISED
OUTPUT
30
26
18
A-D
28
ATTENUATOR
MICROPROCESSOR
19
LIMITED MODULATING SIGNAL
MS
MICROCONTROLLER

F I G . 7

2337884

Voltage Controlled Oscillator

Technical Field

The invention concerns a voltage controlled oscillator.

Background

A voltage controlled oscillator (VCO) is a circuit which is designed to produce an output signal of a particular frequency. This frequency is determined by the level of a voltage which is input to the oscillator. The output frequency of the oscillator can be varied by varying the magnitude of the voltage which is input to the oscillator. Typically, a voltage controlled oscillator may be used to provide a signal for transmission by the transmitter of a communications system.

The output frequency of the VCO can be varied reliably between a certain maximum frequency and a certain minimum frequency. The frequencies between these limits are referred to as the VCO's frequency range. There are however particular requirements for transmitter modulation linearity over a VCO' s frequency range. Prior art designs of VCO often meet these requirements for transmitter modulation linearity only with great difficulty and expense.

A typical VCO design includes a parallel circuit comprising an inductor and a capacitor in the oscillator. Such a design is illustrated in figure 1, which includes an inductor Lp and a capacitor Cp. The frequency of the oscillations produced by the oscillator, for the moment disregarding the other components shown in figure 1, would simply be the resonant frequency of this parallel circuit. The parallel circuit comprising inductor Lp and Cp is shown in figure 1 to lie between a pair of terminals which are labelled 2 and 4 respectively.

Also connected to terminals 2 and 4 is a series circuit comprising a first varactor Ct1 and a coupling capacitor Cc1. Varactor Ct1 functions as a tuning capacitor, which can be tuned to a desired capacitance value by

applying a tuning voltage VS via the lead which bears reference 20. The tuning voltage is otherwise termed the 'steering' voltage. Although Ct1 is a varactor, a VCO can actually be constructed using any tuneable capacitor.

The voltage VS determines the capacitance value of the varactor Ct1. This capacitance value changes the total capacitance between terminals 2 and 4. This change in capacitance changes the resonant frequency of the circuitry connected between terminals 2 and 4, and thereby changes the frequency of the signal output by the VCO. The components illustrated in figure 1 therefore provide an oscillator whose output frequency can be varied by varying the voltage on line 20. This is one basic design of VCO.

The arrangement of figure 1 shows a radio-frequency output from the oscillator 10, which is fed to a synthesiser 12. A further input to the synthesiser 12 is provided by a reference oscillator 14. The output of the synthesiser 12 is fed to a loop filter 16, which provides the control voltage VS.

A further development of this basic VCO design is shown in figure 2. Figure 2 shows the main elements of one of the applicant's prior art VCO circuits.

Figure 2 comprises similar elements to those shown in figure 1. Additionally, figure 2 comprises a further varactor Ct2. A lead VT supplies a voltage to the varactor Ct2. The voltage on line VT provides compensation for the manufacturing tolerances of the components Lp, Cp and Ct1. Capacitor Cc2 is a coupling capacitor which connects varactor Ct2 to terminal 2, thus connecting it in parallel with the basic components Lp, Cp and Ct1 of the VCO.

Components Lp, Cp and Ct1 can only be manufactured with their values and characteristics within certain margins of the intended, optimal values. These margins are the manufacturing tolerances.

In a theoretical circuit, a voltage of, for example, Vnominal volts would need to be supplied on line 20 in order to cause the VCO to produce a given output

signal with a frequency of Fnominal. However, in a practical circuit there are manufacturing tolerances which result in the actual voltage required on line 20 to produce the output signal of frequency Fnominal probably being slightly above or below the theoretical value Vnominal.

The arrangement of figure 2 allows a compensation voltage VT to be fed to varactor Ct2 on line 22 in order to compensate for these manufacturing tolerances. This voltage VT controls the capacitance value of varactor Ct2, and can therefore introduce an offset capacitance between the terminals 2 and 4. The effect of this compensation is to change the frequency which is output by the VCO for a particular input voltage VS on line 20. By choosing the correct value of VT, the VCO can be made to produce the particular output frequency Fnominal in response to a voltage being input on line 20 which is very close to the theoretical voltage Vnominal. Thus compensation for manufacturing tolerances can largely be achieved.

The arrangement of figure 2 includes circuitry to derive the signal VT. This circuitry may include a microcontroller 18, having a microprocessor 19 and a digital-analogue converter to derive the actual voltage level VT for line 22.

In the applicant's prior art design according to figure 2, line 22 could be supplied with any of eight different values of compensation voltage. Each value of this voltage provided optimum compensation for manufacturing tolerances when the VCO was operating in a different part of its operating frequency range.

The operating characteristic of a VCO takes the general form recognisable from figure 3. Figure 3 shows a typical graph of the output frequency of a VCO plotted against the steering voltage VS. As figure 3 shows, the characteristic of the VCO is a curve, rather than a straight line.

The operating frequency range of the VCO of figure 2 has been shown on figure 3 as the portion of the curve between the frequency points marked as Fmin

and Fmax. These frequency points correspond to the voltage VS taking the values Vmin and Vmax respectively.

Figure 3 also shows two dotted lines at voltage values Vtolmin and Vtolmax. These indicate respectively the minimum and maximum voltages VS which might need to be supplied to real circuits of the design shown in figure 1 to provide output frequencies from Fmin to Fmax. These dotted lines highlight the superior accuracy of the compensated arrangement of figure 2 in comparison to the 'un-compensated' arrangement of figure 1.

Although the arrangement of figure 2 provides compensation for manufacturing tolerances, it has the added complexity of a second varactor and coupling capacitor.

In both the arrangements of figure 1 and figure 2, a modulating voltage may be applied to the varactor Ct1. This provides a frequency modulation on the output of the VCO. However, the characteristic of the VCO is a curve, as shown in figure 3. This means that a given magnitude of modulating voltage applied to the varactor will produce a frequency modulation whose magnitude depends on the position on the curve. This makes it very difficult to provide the desired amount of frequency modulation in the VCO's output signal.

In a circuit of the type shown in figure 1 or figure 2, typically, the level of modulating signal applied to the varactor diode Ct1 must be varied across the operating range of the VCO to compensate for the non-uniform deviation sensitivity. An attenuator in the modulation voltage supply line may be used to do this. The modulation signal level that must be applied to a particular varactor to give the required deviation (output frequency modulation) is in fact found in accordance with the prior art by measuring the frequency modulation achieved on the VCO's output signal and adjusting the attenuator accordingly. This is repeated for several segments of the characteristic over which the deviation must be kept at a desired level. Each of these segments can be considered to be a 'tuning bin'. The modulation voltage may also be referred to as the 'audio' level.

Adding the modulating signal to the main control loop voltage is only one way of providing modulation to a VCO. However, such an arrangement is rare because of VCO non-linearity, both across and within the tuning bins.

Current techniques of providing modulation can employ a variable attenuator in the line supplying the modulation voltage. This method involves the following steps:
(i) synthesise a frequency in the first tuning bin, typically at the centre; then
(ii) adjust an electronic attenuator until the desired magnitude of frequency modulation of the output signal measured on a test meter is obtained; then
(iii) store this value in the radio for future use;
(iv) repeat the process for each tuning bin.

Step (ii) involves adjusting the attenuator until a target amount of frequency modulation is obtained. This is under the condition of a known, modulating signal being input to the attenuator whilst the VCO is tuned to the particular frequency bin concerned. The step leads to an empirical setting for the attenuator, this being the setting which is required to provide a pre-determined output frequency deviation.

The method described above is very time consuming. It also requires expensive test equipment in the factory.

Summary of the Invention

The invention provides a method of controlling the magnitude of the frequency modulation on the output signal of a voltage controlled oscillator at an operating frequency F, the magnitude of the frequency modulation depending on the magnitude of a modulation voltage supplied to the control loop of the voltage controlled oscillator, the magnitude of the modulation voltage depending on both the magnitude of a modulating signal supplied to the voltage controlled oscillator and the variable attenuation setting A_F provided by an

attenuator, the modulating signal being supplied through the attenuator to provide the modulation voltage, the method comprising the steps of:

(a) setting the voltage controlled oscillator to operate at a first operating frequency;

(b) measuring a first value of a control voltage, the control voltage being the voltage on the voltage control line of the voltage controlled oscillator, the first value of the control voltage being the value necessary to provide operation at the first operating frequency;

(c) setting the voltage controlled oscillator to operate at a second operating frequency, the second operating frequency differing by only a small frequency increment from the first operating frequency;

(d) measuring a second value of the control voltage necessary to provide operation at the second operating frequency;

(e) calculating the loop sensitivity of the voltage controlled oscillator to changes of the control voltage at the first operating frequency as Kv, the ratio of the difference between the measured frequencies to the difference between the measured voltages;

(f) calculating a first value of the deviation sensitivity of the voltage controlled oscillator at the first operating frequency as

$D1 = K_0 \times Kv$

where K_0 is a constant for the voltage controlled oscillator, the value of K_0 depending on the amount of coupling of a change in the modulating voltage onto the voltage control line;

(g) for the first value of the deviation sensitivity and for a particular maximum level of the modulating signal, calculating a first attenuation setting for the variable attenuator, at the first frequency, the first attenuation setting being the setting of the attenuator which provides a target amount of frequency modulation on the output of the voltage controlled oscillator;

(h) repeating steps (a) to (g) for a variety of operating frequencies distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the attenuation setting at these operating frequencies;

(i) estimating the attenuation setting A_F for an operating frequency F from the values of the attenuation setting derived in steps (a)-(h), and, in operation at output frequency F, setting the attenuator to the attenuation setting A_F to

provide the target amount of frequency modulation on the output signal of the voltage controlled oscillator.

A voltage controlled oscillator arrangement in accordance with the invention comprises:
a resonant circuit and a tuneable capacitor;
a synthesiser, loop filter and voltage control line, whereby in operation of the voltage controlled oscillator arrangement, the synthesiser and loop filter generate a control voltage on the voltage control line, and the control voltage on the voltage control line is fed to the tuneable capacitor;
a microcontroller, comprising a microprocessor and measurement circuitry for measuring a voltage representative of the voltage on the voltage control line;
a variable attenuator for supplying a modulating voltage via a line, through the loop filter, to the voltage control line, the variable attenuator being connected to the microcontroller;
whereby in operation of the voltage controlled oscillator arrangement at an operating frequency F, the microprocessor sets the attenuation setting A_F of the variable attenuator, the microprocessor estimating the required attenuation setting A_F for an operating frequency F based on calculations of the attenuation setting for calculated values of the loop sensitivity Kv of the voltage controlled oscillator, the calculated values of the loop sensitivity Kv being based on measurements at various frequencies over the operating frequency range of the voltage controlled oscillator arrangement.

The present invention also encompasses a method of estimating the deviation sensitivity D_F of a voltage controlled oscillator at an operating frequency F, modulation of the output signal of the voltage controlled oscillator being provided by a modulation voltage, the method comprising the steps of:
(a) setting the voltage controlled oscillator to operate at a first operating frequency;
(b) measuring a first value of a control voltage, the control voltage being the voltage on the voltage control line of the voltage controlled oscillator, the first value of the control voltage being the value necessary to provide operation at the first operating frequency;

(c) setting the voltage controlled oscillator to operate at a second operating frequency, the second operating frequency differing by only a small frequency increment from the first operating frequency;

(d) measuring a second value of the control voltage necessary to provide operation at the second operating frequency;

(e) calculating the loop sensitivity of the voltage controlled oscillator to changes of the control voltage at the first operating frequency as Kv, the ratio of the difference between the measured frequencies to the difference between the measured voltages;

(f) calculating a first value of the deviation sensitivity of the voltage controlled oscillator at the first operating frequency as

$D1 = K_0 \times Kv$

where K_0 is a constant for the voltage controlled oscillator, the value of K_0 depending on the amount of coupling of a change in the modulating voltage onto the voltage control line;

(g) repeating steps (a) to (f) for a variety of operating frequencies distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the deviation sensitivity at these operating frequencies;

(h) estimating the deviation sensitivity D_F of the voltage controlled oscillator for an operating frequency F from the values of the deviation sensitivity derived in steps (a)-(g).

Steps and features of further preferred embodiments of the invention are recited in the dependent claims.

Brief description of the drawings

Figure 1 shows a schematic view of a basic voltage controlled oscillator (VCO) circuit of the prior art.

Figure 2 shows a schematic view of a further VCO circuit of the prior art.

Figure 3 shows a graph of VCO output frequency plotted against the steering voltage VS.

Figure 4 shows a voltage controlled oscillator in accordance with the invention.

Figure 5 shows an example of a loop filter suitable for use in the arrangement of figure 4.

Figure 6 illustrates a measurement step performed at a particular VCO operating frequency in the method of the invention.

Figure 7 shows a further voltage controlled oscillator in accordance with the invention.

Detailed description of the preferred embodiment

Figure 4 shows an arrangement in accordance with the present invention. Elements of figure 4 which have been described in connection with figures 1 and 2 will not be described again here.

The arrangement of figure 4 contains a microprocessor 19 which forms part of a microcontroller 18, analogously to the arrangement of figure 2. However, the arrangement of figure 4 also includes an attenuator 28 under the control of microprocessor 19. The output of attenuator 28 is fed by line 30 to the loop filter 16.

The modulating signal MS which provides frequency modulation on the output of the VCO is fed to the input of the attenuator 28. This input signal to the attenuator can be assumed to be of limited maximum magnitude. The output from the attenuator 28 is a voltage signal VM. Signal VM is fed to the loop filter 16. The output of loop filter 16 is a voltage VC. Voltage VC is the tuning signal which is fed on voltage control line 20 to the varactor Ct1.

A VCO in accordance with the invention comprises a varactor Ct1 to which both the traditional 'steering line' voltage from synthesiser 12 and a voltage

derived from the modulating voltage VM are fed as a combined signal. In the arrangement of figure 4, this combined signal is voltage VC on line 20.

The output signals from the synthesiser 12 and the attenuator 28 are combined in the loop filter 16 to provide the voltage VC. Figure 5 shows an example of a loop filter which can combine these signals. The output of the attenuator 28 is supplied to capacitor C1 in the loop filter. On being input to the loop filter, the modulating voltage VM fed from attenuator 28 is reduced in magnitude in the ratio C1/(C1+C2) by the arrangement of capacitors C1 and C2. The output of the synthesiser 12 is fed to the loop filter 16 on the line shown at the top right of the filter.

Besides voltage control line 20, loop filter 16 has a further output line 40, shown on figure 4. Loop filter 16 outputs a voltage signal VB on line 40. The voltage signal VB is representative of the voltage VC on line 20. Voltage VB is fed to a buffer circuit 24. The output of buffer circuit 24 is measured by an A/D converter 26 and is fed to the microprocessor 19.

The invention involves determining the sensitivity of the VCO at different points on its frequency/voltage curve. Knowing this enables calculation of the optimum attenuator setting A_F at any VCO operating frequency F. The optimum attenuator setting A_F is the setting which results in the optimum modulating voltage VM being supplied to loop filter 16 in order to provide the desired amount of frequency modulation on the VCO's output. The sensitivity of the VCO is dependent on the sensitivity of the varactor Ct1, this being the amount of change in the varactor's capacitance per unit change in the voltage supplied to it.

Calculation of the optimum attenuator setting A_F at all VCO operating frequencies F requires knowledge of the sensitivity of the VCO at all steering voltages. The calculation itself requires both empirical steps and calculation. The empirical part of this method involves measuring the sensitivity of the VCO at a number of operating frequencies spaced along the VCO's operating frequency range. Then in normal operation of the VCO, an algorithm can be

used to calculate the optimum attenuator setting A_F at the point on the VCO's characteristic where it is currently operating.

A special test system command could initiate the measurement of the VCO's sensitivity. This could be done very rapidly in the factory. Alternatively, the radio could perform this measurement cycle every time that it is powered up. This measurement can also be performed at other times, for example when the radio loses lock. This is particularly advantageous for simple VCOs which are inherently non-linear. It is also particularly advantageous for radio designs which use many frequency segments to cover the desired operating frequency range, i.e. many 'tuning bins'.

In accordance with the invention., the initial measurement of the sensitivity of the VCO at a particular frequency is determined by the following steps (a)-(c), which should be read in conjunction with figure 6. For the purposes of this measurement, no modulating signal need be applied, i.e. VM = 0.

(a) Firstly, the VCO is set to operate at a particular frequency F1. The value of voltage VC necessary to provide operation at this frequency F1 is measured. Assume that this measurement step yields a value for VC of V1 at frequency F1.

(b) Now the VCO's operating point, i.e. operating frequency, is moved a small amount. This is done by moving the steering line voltage a small amount, which in turn is achieved by varying the desired synthesised frequency from synthesiser 12 by a small amount. Assume that after this change the VCO is now operating at frequency F2, and that the measured value of VC is now V2.

(c) The sensitivity of the varactor to changes of the voltage VC can now be calculated. This is the loop sensitivity Kv. This is equal to:

$$Kv = (F2-F1)/(V2-V1)$$

The value of Kv is a measure of the amount of change in the output frequency F of the oscillator provided by a given change in the voltage VC on line 20. To a close approximation, this is the slope of the operating characteristic of the VCO in figure 6.

However, in operation the circuit of figure 4 supplies its modulating signal via attenuator 28 and loop filter 16 to the line 20.

The effect of a change in the voltage VM output by the attenuator 28 on voltage VC depends on the amount of coupling of the voltage through loop filter 16. This coupling can be treated as a constant K_0. In practice, K_0 may depend simply on the ratio of the values of two components in the path through the loop filter connecting leads 30 and 20. These might be two resistors or two capacitors. In the loop filter illustrated in figure 5, these are the capacitors C1 and C2.

Knowing Kv, the sensitivity of the VCO to changes in the voltage VM at frequency F can now be calculated. This is the deviation sensitivity D. The value of D at frequency F is

$$D = K_0 \times Kv$$

Using the value of Kv calculated at frequency F1, this equation yields a value D1 for the deviation sensitivity at VCO operating frequency F1.

The modulation voltage VM required to provide a desired frequency modulation on the VCO's output at frequency F1 can now be calculated as follows:

Required deviation voltage = Target frequency deviation / D

= Target frequency deviation / (K_0 x Kv)

The amplitude of the modulating signal input to attenuator 28 is constant for the particular radio. Therefore an attenuation setting A1 for the attenuator at

frequency F1 can be calculated simply by knowing this amplitude and the required deviation voltage at frequency F1. The above calculation can clearly lead therefore to an attenuation setting A of attenuator 28 at any frequency F for which the loop sensitivity has been determined.

Steps (a) to (c) are now repeated for each of a number of different VCO output frequencies such as F3, F5,....Fn. These frequency values should be distributed over the operating frequency range of the VCO. The resulting values of Kv are then representative of the loop sensitivity over the whole operating range of the VCO, i.e. over an entire curve such as that shown in figure 6. Similarly therefore, the values of the attenuator setting A3, A5...An calculated for these frequencies are representative of the whole operating range of the VCO.

The initial measurement steps outlined above provide information about the characteristics of the characteristic curve shown in figure 6. Specifically, the loop sensitivities at measurement frequencies F1, F3, F5...Fn have been measured and the corresponding attenuator settings A1, A3, A5...An calculated.

In normal operation of the VCO, the attenuator should be set to the optimum value A_F at any operating frequency of the VCO, not just at the points such as F1, F3, F5,.. Fn which were measured in the initial measurement steps. The arrangement of the invention can do this in various different ways.

In a preferred embodiment of the invention, the arrangement calculates the attenuator setting needed for any chosen VCO operating frequency. The attenuator setting A_F is calculated from measurements at two nearby frequencies where the sensitivity has been measured, one frequency lying above A_F and the other below. An algorithm interpolates between the two known attenuation settings A1, A3, A5...An, at the two nearby frequencies. This technique can be used at all operating frequencies in the VCO's operating range to derive the value of the attenuator setting A_F which provides the desired amount of frequency modulation at frequency F.

This embodiment can be understood in detail by considering the following short algorithm of steps (i)- (iii) below. This algorithm assumes that the radio has measured the VCO sensitivity at the top and bottom frequency values of a number of frequency bins. A detailed algorithm for doing this preliminary measurement is shown in appendix 1 at the end of this description. The radio would employ an algorithm consisting of the following steps to determine the attenuator value to use at any frequency F:

(i) Starting from the chosen operating frequency F of the radio, work out which frequency bin this frequency lies in via a look up-table or 'bin-pointer';
(ii) Work out where within this bin the VCO is operating, relative to the top and bottom limits of that frequency bin; and
(iii) Interpolate between the upper and lower calculated attenuation values for the selected bin.

In an alternative embodiment of the invention, a curve fitting algorithm can be employed instead of the interpolation technique. In the curve fitting embodiment, a software algorithm calculates the 'best fit' curve to the values of attenuation settings A1, A2, A3...An which were measured for the VCO in the initial measurement step. The value of attenuation setting A_F required at any VCO operating frequency F can then be calculated simply from this curve.

It is notable that these two embodiments outlined above may not lead to the same attenuator setting A_F for a given VCO operating frequency F. However, the accuracy of the frequency modulation achievable by the attenuator 28 is in any case limited by the resolution of the attenuator. The attenuator might typically be able to take on one of 256 different settings under the control of microprocessor 19. This coarseness limits the precision to which the frequency modulation of the VCO can be set.

In operation, the microcontroller of the present invention can select the attenuator setting A_F calculated to best suit any operating frequency F within

its operating frequency range. When a radio incorporating this arrangement is tuned to a particular frequency, the microcontroller uses this frequency to either interpolate or calculate the optimum attenuator setting. This setting is then supplied to attenuator 28. This attenuator setting is then used until the VCO is re-tuned to an operating frequency sufficiently different from the initial frequency that the microcontroller decides that a different attenuator setting is necessary to provide the desired amount of frequency modulation. This new attenuator setting is then used.

The arrangement offers several advantages. These include the following:

1. The VCO's variable modulation deviation sensitivity is compensated for automatically each time that the method of the invention is applied.
2. Tuning takes very little time. This is because the tuning is performed under radio control with no remote control.
3. Because the deviation is adjusted optimally every time, the effect of component ageing tolerances is eliminated.
4. Because the VCO is adjusted optimally every time, the effect of component variations with temperature is eliminated.

The arrangement of figure 4 shows a single varactor Ct1. However, the invention can also be employed in an arrangement which comprises a further varactor. Such an arrangement is shown in figure 7.

The further varactor Ct3, and a coupling capacitor Cc3, can be connected between terminals 2 and 4, in a similar fashion to varactor Ct1 and coupling capacitor Cc1. The further varactor is then fed via a line 50 with one of a series of discrete voltages produced by the microcontroller 18. Each discrete voltage provides a discrete capacitance increment to the oscillator, thereby determining in 'coarse' increments the point on the oscillator's characteristic at which the oscillator operates. Each discrete voltage fed to this further varactor Ct3 thus selects a different 'frequency bin' within which the VCO operates.

In this arrangement, the first varactor Ct1 is fed with voltages which vary over a comparatively narrow range. This narrow range is less than the whole operating frequency range of the VCO, and determines the exact operating frequency of the oscillator within the frequency bin which has been selected by the voltage fed to the further varactor Ct3.

Applying the invention to this arrangement, the empirical measurement of the loop sensitivity Kv and the Deviation sensitivity are performed at least once within each frequency bin set by varactor Ct3. Preferably, two such measurements are performed within each frequency bin, at frequencies around the top and bottom of the bin. In operation then, an estimate of the attenuator setting A_F can be made at any operating frequency F by interpolation between these measured values within the bin.

The VCO arrangement and the method of the invention may be used in a portable- or a mobile radio, or in a mobile telephone.

Appendix 1

The following algorithm is an example falling within the terms of the invention. This algorithm provides measured values of the VCO loop sensitivity and attenuator setting for frequencies at the top and bottom of each of a number of frequency bins. These bins span the VCO's operating frequency range.

1. Set synthesiser to desired lowest frequency Fbl in bin = F(1)
2. Measure VC= VClow1
3. Set synthesiser to frequency Fb2, equal to frequency F(1) plus a small offset.
4. Measure VC= VClow2
5. Calculate loop sensitivity Kv= (Fb2-Fb1)/(VClow2-VClow1)
6. Calculate corresponding Deviation sensitivity = K_0 x Kv, where K_0 is the ratio of 2 resistors in the VCO.

7. Calculate required deviation voltage
= Target Frequency Deviation/ (K_0 x Kv)
8. Calculate required attenuator setting to give required deviation voltage. The unattenuated modulating amplitude is known for a given radio design. The tolerance errors are very small with modern components.
9. Store required attenuator setting for the bottom of this bin as Ab1.
10. Repeat steps 1-9 for a frequency at the top of the tuning bin, replacing Fb1, Fb2, VClow1, VClow2 and Ab1 with respectively Ft1, Ft2, VCtop1, VCtop2 and At1. At1 is the required attenuation for the top of the bin.
11. Repeat steps 1-10 for other frequency bins.
12. The radio now has accurate attenuator settings at selected frequencies over its tuning range.

Claims

1. A method of controlling the magnitude of the frequency modulation on the output signal of a voltage controlled oscillator at an operating frequency F, the magnitude of the frequency modulation depending on the magnitude of a modulation voltage (VM) supplied to the control loop of the voltage controlled oscillator, the magnitude of the modulation voltage (VM) depending on both the magnitude of a modulating signal (MS) supplied to the voltage controlled oscillator and the variable attenuation setting A_F provided by an attenuator (28), the modulating signal (MS) being supplied through the attenuator (28) to provide the modulation voltage (VM), the method comprising the steps of:

(a) setting the voltage controlled oscillator to operate at a first operating frequency (F1);

(b) measuring a first value (VC1) of a control voltage (VC), the control voltage (VC) being the voltage on the voltage control line (20) of the voltage controlled oscillator, the said first value (VC1) of the control voltage being the value necessary to provide operation at the said first operating frequency (F1);

(c) setting the voltage controlled oscillator to operate at a second operating frequency (F2), the second operating frequency (F2) differing by only a small frequency increment from the first operating frequency (F1);

(d) measuring a second value (VC2) of the control voltage (VC) necessary to provide operation at the said second operating frequency (F2);

(e) calculating the loop sensitivity (Kv) of the voltage controlled oscillator at the said first operating frequency (F1) to changes of the control voltage (VC) as

$$Kv = (F2-F1)/(V2-V1)$$

(f) calculating a first value of the deviation sensitivity (D1) of the voltage controlled oscillator at the said first operating frequency (F1) as

$D1 = K_0 \times Kv$

where K_0 is a constant for the voltage controlled oscillator, the value of K_0 depending on the amount of coupling of a change in the modulating voltage (VM) onto the voltage control line (20);

(g) for the said first value of the deviation sensitivity (D1) and for a particular maximum level of the modulating signal (MS), calculating a first attenuation setting (A1) for the said variable attenuator (28), at the said first frequency (F1), the first attenuation setting (A1) being the setting of the attenuator (28) which provides a target amount of frequency modulation on the output of the voltage controlled oscillator;

(h) repeating steps (a) to (g) for a variety of operating frequencies (F3, F5...Fn) distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the attenuation setting (A3, A5,...An) at these operating frequencies (F3, F5,...Fn);

(i) estimating the attenuation setting A_F for an operating frequency F from the values of the attenuation setting (A1, A3, A5,...An) derived in steps (a)-(h), and, in operation at output frequency F, setting the attenuator to the attenuation setting A_F to provide the said target amount of frequency modulation on the output signal of the voltage controlled oscillator.

2. A method in accordance with claim 1, wherein, in operation of the voltage controlled oscillator, the modulating signal (MS) is magnitude limited, and the particular maximum level used in the calculation of step (g) is the magnitude which the modulating signal (MS) cannot exceed.

3. A method in accordance with claim 1 or claim 2, whereby step (i) further comprises interpolating between the values of the attenuation setting (A1,

A3, A5,..An) derived for the next nearest frequencies (F1, F3, F5,...Fn) above and below frequency F, to estimate the attenuation value A_F.

4. A method in accordance with claim 1 or claim 2, whereby step (i) further comprises fitting a curve to the derived values of the attenuation setting (A1, A3, A5,..An) and estimating the value of attenuation setting A_F for the operating frequency F from the said curve.

5. A method in accordance with any of claims 1-4, wherein the value of K_0 depends on the values of two capacitors C1 and C2 in the path of the modulating voltage (VM) to the voltage control line (20).

6. A method in accordance with any of claims 1-5, wherein the attenuator (28) is controlled digitally, and is set to the nearest digital value to the estimated attenuation setting A_F.

7. A voltage controlled oscillator arrangement, comprising:

a resonant circuit (Lp, Cp) and a tuneable capacitor (Ct1);

a synthesiser (12), loop filter (16) and voltage control line (20), whereby in operation of the voltage controlled oscillator arrangement, the said synthesiser (12) and said loop filter (16) generate a control voltage (VC) on the said voltage control line (20), and the control voltage (VC) on the said voltage control line (20) is fed to the said tuneable capacitor (Ct1);

a microcontroller (18), comprising a microprocessor (19) and measurement circuitry (24, 26) for measuring a voltage (VB) representative of the voltage (VC) on the said voltage control line (20);

a variable attenuator (28) for supplying a modulating voltage (VM) via a line (30), through said loop filter (16), to the said voltage control line (20), the variable attenuator (28) being connected to said microcontroller (18);

whereby in operation of the voltage controlled oscillator arrangement at an operating frequency F, the microprocessor (19) sets the attenuation setting A_F of the said variable attenuator (28), the said microprocessor (19) estimating the required attenuation setting A_F for an operating frequency F based on calculations of the attenuation setting (A1, A3, A5,...An) for calculated values of the loop sensitivity Kv of the voltage controlled oscillator, the calculated values of the loop sensitivity Kv being based on measurements at various frequencies (F1, F3, F5,...Fn) over the operating frequency range of the voltage controlled oscillator arrangement.

8. A voltage controlled oscillator arrangement in accordance with claim 7, wherein the microprocessor (19) estimates the required attenuation setting A_F for an operating frequency F by interpolation between calculated values for the attenuation setting (A1, A3, A5, ...An) at the next nearest frequencies (F1, F3, F5,...Fn) above and below operating frequency F.

9. A voltage controlled oscillator arrangement in accordance with claim 7 or claim 8, wherein the said tuneable capacitor (Ct1) is a varactor, and further comprising a further varactor (Ct3) connected in parallel to the said resonant circuit (Lp, Cp), whereby in operation of the voltage controlled oscillator one of a set of discrete voltages is fed to the said further varactor (Ct3) by the microcontroller (18) to provide a frequency bin within which the voltage controlled oscillator operates, the first said varactor (Ct1) being fed with a control voltage (VC) variable over a comparatively narrow range to determine the exact operating frequency F of the voltage controlled oscillator within the selected frequency bin.

10. A method of estimating the deviation sensitivity D_F of a voltage controlled oscillator at an operating frequency F, modulation of the output signal of the voltage controlled oscillator being provided by a modulation voltage (VM), the method comprising the steps of:

(a) setting the voltage controlled oscillator to operate at a first operating frequency (F1);

(b) measuring a first value (VC1) of a control voltage (VC), the control voltage (VC) being the voltage on the voltage control line (20) of the voltage controlled oscillator, the said first value (VC1) of the control voltage being the value necessary to provide operation at the said first operating frequency (F1);

(c) setting the voltage controlled oscillator to operate at a second operating frequency (F2), the second operating frequency (F2) differing by only a small frequency increment from the said first operating frequency (F1);

(d) measuring a second value (VC2) of the control voltage (VC) necessary to provide operation at the said second operating frequency (F2);

(e) calculating the loop sensitivity (Kv) of the voltage controlled oscillator at the said first operating frequency (F1) to changes of the control voltage (VC) as

$$Kv = (F2-F1)/(V2-V1)$$

(f) calculating a first value of the deviation sensitivity (D1) of the voltage controlled oscillator at the said first operating frequency (F1) as

$$D1 = K_0 \times Kv$$

where K_0 is a constant for the voltage controlled oscillator, the value of K_0 depending on the amount of coupling of a change in the modulating voltage (VM) onto the voltage control line;

(g) repeating steps (a) to (f) for a variety of operating frequencies (F3, F5...Fn) distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the deviation sensitivity (D3, D5,...Dn) at these operating frequencies (F3, F5,...Fn);

(h) estimating the deviation sensitivity D_F of the voltage controlled oscillator for an operating frequency F from the values of the deviation sensitivity (D1, D3, D3,...Dn) derived in steps (a)-(g).

11. A method in accordance with claim 10, whereby step (h) further comprises interpolating between the derived values of deviation sensitivity (D1, D3, D5...Dn) at the next nearest frequencies (F1, F3, F5...Fn) above and below frequency F to estimate the value of the deviation sensitivity D_F for operating frequency F.

12. A method in accordance with claim 10, whereby step (h) further comprises fitting a curve to the derived values of deviation sensitivity (D1, D3, D5...Dn) and estimating the value of the deviation sensitivity D_F at operating frequency F from the said curve.

13. A method in accordance with any of claims 10-12, wherein the value of K_0 depends on the values of two capacitors C1 and C2 in the path of the modulating voltage (VM) to the voltage control line (20).

14. A voltage controlled oscillator arrangement substantially as hereinbefore described with reference to, or as illustrated by, any of figures 4,6 or 7 of the drawings.

The Patent Office

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H3A: AE; H3R: RFMA; G1U:UR2906

Int Cl (Ed.6): G01R, H03C, H03L

Other: Online: WPI, JAPIO, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 4309674 OWEN - see especially figures 2,3 and columns 2-4	1, 7 and 10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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